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# AZUSA PLANT

STRUCTURAL MATERIALS DIVISION

## INVESTIGATION OF STRESS-CORROSION CRACKING OF HIGH-STRENGTH ALLOYS

A REPORT TO
FRANKFORD ARSENAL

CONTRACT DA-04-495-ORD-3069

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AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

This is the twentieth in a series of informal progress reports submitted in partial fulfillment of Contract DA-04-495-ORD-3069. It covers the period 1 November through 30 November 1962.

AEROJET-GENERAL CORPORATION

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NOTE: The information contained herein is regarded as preliminary and subject to further checking, verification, and analysis.

## I. OBJECTIVES

The objectives of this program are:

A. To investigate the stress-corrosion cracking characteristics of at least three new high-strength alloys of interest for applications to rocket motor cases. These alloys are 6Al-4V titanium, 18%-nickel maraging steel, and 20% nickel-maraging steel; in addition, limited testing of vacuum melted 9Ni-4Co steel will be done.

B. To study the environmental parameters that could affect the rate and extent of stress-corrosion cracking

C. To determine the effect of material parameters (composition, strength level, welding, and microstructure) on stress-corrosion susceptibility

D. To continue the evaluation of protective coatings and other techniques for preventing stress-corrosion cracking.

## II. SUMMARY

The third year's program is in progress with bent-beam and center-notched specimens of 6Al-4V titanium under test. Both the annealed and the quenched-and-aged conditions are being evaluated. No cracking has been observed to date. The 20%-nickel maraging steel and the "high-titanium" 18%-nickel maraging steel will be in test in early January. Mill difficulties in producing satisfactory heats of the other test materials will hold up their delivery until early February.

## III. WORK PROGRESS

Work is continuing along the guidelines of the master program chart (Table 1). Work progress to date is described in the following paragraphs.

A. 6Al-4V TITANIUM

The chemical composition and mechanical properties of the heat of 6Al-4V titanium under test have been determined and are shown in Table 2. Bent-beam tests are now under way in all environments except the sea-coast exposure for both annealed and heat-treated samples. Sea-coast exposure will begin within one month. One-hundred-hour testing of center-notched annealed samples is almost complete. Heat-treated, center-notched samples are now ready for testing. Welded specimens have been prepared, and these samples will be in test early in January. Of all the specimens under test, no failures have been observed to date.

B. 20%-NICKEL MARAGING STEEL

The chemical composition and mechanical properties of the two sheets of 20%-nickel maraging steel received have been determined; results are shown in Table 3. These sheets, representing items H-1 and H-3 in Table 3, are the annealed and the 75% cold-worked materials. The -100°F refrigeration treatment prior to aging of annealed material has been found to give a yield strength of over 290,000 psi, which is approximately 5000 psi higher than the yield strength of the material which was aged without a prior refrigeration treatment. This is in accordance with information obtained from the International Nickel Co. Bent-beam samples of the annealed-and-aged and the 75% cold-worked-and-aged materials will be in test within one week; some data will be available by the next quarterly report. The center-notch tests will be started in late January. It has been learned that the 50% cold-worked material is now scheduled for shipment in mid-February. The delay in shipment was caused by difficulty at the mill in producing a satisfactory heat.

C. 18%-NICKEL MARAGING STEEL

Only one of the three heats scheduled for shipment has been received (Material I-3 in Table 1). This is the 50% cold-worked material containing from 0.6 to 1.0% titanium. The titanium content of 18%-nickel maraging steel has a direct effect on the mechanical properties attainable;

the 0.6-to-1.0% material, considered "high-titanium," would be expected to show higher yield strengths than the "low-titanium" material (0.3-0.6%). The heat of this alloy which has been received shows a titanium content of 0.62% and a yield strength in the aged condition of 323,800 psi.

Bent-beam, stress-corrosion testing of this material will start within the next week. The remaining two sheets of this alloy, representing the 0% and 50% cold-worked "low-titanium" material, have been rescheduled for delivery in early February. Delay of shipment has been caused by mill errors in the manufacturing process, in which two defective heats were produced.

D. 9-NICKEL/4-COBALT ALLOY

Shipment of this alloy has also been held up at the mill. Shipment of material with two levels of carbon (0.25 to 0.30% and 0.40 to 0.45%) has been promised for early February.

E. COATING EVALUATION

The evaluation of protective coatings is continuing and will be conducted throughout the program duration. Three coatings were evaluated during the first two-year program; five or six more will be tested during the third year. The base material for the coating evaluation is H-11 steel, which has been shown to be highly susceptible to stress-corrosion cracking. Successful coatings will again be evaluated on the maraging steels, if these steels are found to be susceptible to stress-corrosion cracking. The next quarterly report will contain results of the coating program to that date.

## IV. FUTURE WORK

Testing of all alloys on hand will continue. Every effort will be made to expedite the delivery of materials not yet received. The coating evaluation will be continued and results will be shown in the next quarterly report.

# TABLE 1

## INVESTIGATION OF STRESS CORROSION CRACKING OF HIGH STRENGTH ALLOYS

### Third-Year Program

| Alloy | Anticipated 0.2% Yield Strength* | Possible Heat Treatment | Test Method | Code | Distilled Water (-01) | Water (-02) | 3% NaCl (-03) | Sodium Dichromate Solution (-04) | Soluble Oil (-05) | High Humidity (-06) | Trichloro-ethylene (-07) | Cosmoline (-08) | Solid Propellant (-09) | Air (-10) | Sea Coast Exposure (-11) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6Al-4V Titanium | 135,000 | As received, annealed | Bent Beam | G-1-B | 3** | 3 | 3 | 3 | 3 | 3 | - | 3 | 3 | 3 | 3 |
| | | | U-Bend | G-1-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| | | | Center Notch | G-1-C | 2 | - | 2 | 2 | 2 | - | - | - | - | 2 | - |
| | 170,000 | 1650°F WQ and 900°F age | Bent Beam | G-2-B | 3 | 3 | 3 | 3 | 3 | 3 | - | 3 | 3 | 3 | 3 |
| | | | U-Bend | G-2-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| | | | Center Notch | G-2-C | 2 | - | 2 | 2 | 2 | - | - | - | - | 2 | - |
| | 110,000 | Welded, 900°F age | Bent Beam | G-W-B | 3 | 3 | 3 | 3 | 3 | 3 | - | 3 | 3 | 3 | 3 |
| | | | U-Bend | G-W-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| 20-Nickel Maraging Steel | 250,000 | Solution anneal -100°F, 850°F age | Bent Beam | H-1-B | 3 | 3 | 3 | 3 | 3 | 3 | | 3 | 3 | 3 | 3 |
| | | | U-Bend | H-1-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| | | | Center Notch | H-1-C | 2 | | 2 | 2 | 2 | - | - | - | - | 2 | - |
| | 275,000 | 50% CW 850°F age | Bent Beam | H-2-B | 3 | 3 | 3 | 3 | 3 | 3 | | 3 | 3 | 3 | 3 |
| | | | U-Bend | H-2-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| | | | Center Notch | H-2-C | 2 | - | 2 | 2 | 2 | - | - | - | - | 2 | - |
| | 300,000 | 75% CW 850°F age | Bent Beam | H-3-B | 3 | 3 | 3 | 3 | 3 | 3 | | 3 | 3 | 3 | 3 |
| | | | U-Bend | H-3-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| | | | Center Notch | H-3-C | 2 | - | 2 | 2 | 2 | - | - | - | - | 2 | - |
| | 250,000 | Welded | Bent Beam | H-W-B | 3 | 3 | 3 | 3 | 3 | 3 | - | 3 | 3 | 3 | 3 |
| | | | U-Bend | H-W-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| 13-NiMoCo Maraging Steel | 270,000 | 0% CW 0.3/0.6 % Ti Aged at 900°F | Bent Beam | I-1-B | 3 | 3 | 3 | 3 | 3 | 3 | - | 3 | 3 | 3 | 3 |
| | | | U-Bend | I-1-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| | | | Center Notch | I-1-C | 2 | | 2 | 2 | 2 | - | - | - | - | 2 | - |
| | 300,000 | 50% CW 0.3/0.6% Ti Aged at 900°F | Bent Beam | I-2-B | 3 | 3 | 3 | 3 | 3 | 3 | - | 3 | 3 | 3 | 3 |
| | | | U-Bend | I-2-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| | | | Center Notch | I-2-C | 2 | - | 2 | 2 | 2 | - | - | - | - | 2 | |
| | 320,000 | 50% CW 0.6/1.0% Ti Aged at 900°F | Bent Beam | I-3-B | 3 | 3 | 3 | 3 | 3 | 3 | - | 3 | 3 | 3 | 3 |
| | | | U-Bend | I-3-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| | | | Center Notch | I-3-C | 2 | - | 2 | 2 | 2 | - | - | - | - | 2 | |
| | No data on hand | 0.3/0.6% Ti Welded | Bent Beam | I-W-B | 3 | 3 | 3 | 3 | 3 | 3 | - | 3 | 3 | 3 | 3 |
| | | | U-Bend | I-W-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| 9Ni-4Co Vacuum-Cast Alloy | No data on hand | Aged 0.25%/0.30% C | Bent Beam | J-I-B | 3 | 3 | 3 | 3 | 3 | 3 | - | 3 | 3 | 3 | 3 |
| | | | U-Bend | J-I-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| | | | Center Notch | J-I-C | 2 | | 2 | 2 | 2 | - | - | - | - | 2 | |
| | No data on hand | Aged 0.40/0.45% C | Bent Beam | J-2-B | 3 | 3 | 3 | 3 | 3 | 3 | - | 3 | 3 | 3 | 3 |
| | | | U-Bend | J-2-U | - | - | - | - | - | 3 | 3 | - | - | - | 3 |
| | | | Center Notch | J-2-C | 2 | - | 2 | 2 | 2 | - | - | - | - | 2 | - |

*Based on suppliers' bulletins and/or previous Aerojet data.

**Number refers to number of tests.

TABLE 2

CHEMICAL ANALYSIS AND MECHANICAL PROPERTIES OF 6Al-4V TITANIUM

| | Chemical Analysis* (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | C | Al | V | $O_2$ | $N_2$ | $H_2$ | Ti | Fe | Other |
| Aerojet Analysis | 0.03 | 6.1 | 4.1 | 0.083 | 0.014 | 0.008 | bal. | 0.16 | 0.18 |

| | Mechanical Properties (Transverse) | | | |
|---|---|---|---|---|
| Processing Condition | Yield Strength (0.2% offset) psi | Ultimate Strength psi | Elongation % | Hardness $R_c$ |
| Annealed | | | | |
| Mill Report | 131,900 | 141,400 | 12 | 33.5 |
| Aerojet Test | 138,000 | 143,800 | 14 | 34. |
| 1675°F, 1 hr., W.Q., aged 900°F 8 hrs | | | | |
| Aerojet Test | 162,700 | 176,800 | 7 | 38.5 |

*Titanium Metals Corp., HT 4141.

TABLE 3

CHEMICAL ANALYSIS AND MECHANICAL PROPERTIES
OF 20%-NICKEL MARAGING STEEL

| Chemical Analysis (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C | Mn | P | S | Si | Ni | Al | Cb | Zr | Ti | Ca | B |
| 0.009 | 0.09 | 0.002 | 0.005 | 0.06 | 20.31 | 0.29 | 0.39 | 0.002 | 1.40 | 0.004 | 0.003 |

| | Mechanical Properties (Transverse) | | | |
|---|---|---|---|---|
| Processing Condition | Yield Strength (0.2% offset) psi | Ultimate Strength psi | Elongation % | Hardness $R_c$ |
| Annealed | | | | |
| Mill Report | 123,280 | 166,560 | 7.0 | 34. |
| Aerojet Test | 128,500 | 170,700 | 7.5 | 34. |
| Annealed and Aged 4 hrs at 850°F | | | | |
| Mill Report* | 277,290 | 286,440 | 3. | 55. |
| Aerojet Test | 286,900 | 298,000 | 3.5 | 53.5 |
| Annealed, -100°F 2 hrs, 4 hrs 850°F | | | | |
| Aerojet Test | 291,300 | 302,200 | 3. | 54. |
| 75% C.W. | | | | |
| Mill Report | 205,560 | 218,330 | 4. | 42. |
| Aerojet Test | 205,700 | 220,900 | 6. | 44. |
| 75% C.W. and Aged at 850°F 4 hrs | | | | |
| Aerojet Test | 298,300 | 308,800 | | 55. |
| 75% C.W., -100°F 2 hrs and 850° 4 hrs | | | | |
| Aerojet Test | 298,100 | 305,500 | | 54.5 |

*Aging temperature not shown in mill report.

TABLE 4

CHEMICAL ANALYSIS AND MECHANICAL PROPERTIES
OF 18%-NICKEL MARAGING STEEL WITH "HIGH TITANIUM"

| Chemical Analysis | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | Mn | P | S | Si | Ni | Mo | Ca | Zr | Ti | Co | B | Al |
| 0.012 | <0.01 | 0.003 | 0.005 | <0.01 | 18.69 | 4.92 | 0.006 | 0.003 | 0.62 | 8.90 | 0.002 | 0.029 |

| | Mechanical Properties (Transverse) | | | |
|---|---|---|---|---|
| Processing Condition | Yield Strength (0.2% offset) psi | Ultimate Strength psi | Elongation % | Hardness $R_c$ |
| Annealed | | | | |
| Mill Report | 126,400 | 155,730 | 6.0 | 33 |
| Annealed and Aged | | | | |
| Mill Report* | 277,720 | 284,390 | 3.0 | 56 |
| 50% C.W. | | | | |
| Mill Report | 158,320 | 176,150 | 3.5 | 36 |
| Aerojet Test | 167,700 | 189,000 | 3.5 | 36.5 |
| 50% C.W. and Aged 3 hrs at 900°F | | | | |
| Aerojet Test | 323,800 | 328,400 | 1.5 | 55 |

*Aging treatment not shown in mill report.